

The Osmotic Pressure of Glucose Solutions.

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF
THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY
WITH THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY.

BY

BENJAMIN F. LOVELACE

BALTIMORE

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EASTON, PA. :
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The Osmotic Pressure of Glucose Solutions.

This work constitutes a part of the investigation which has been in progress in this laboratory for a number of years on the general problem of osmotic pressure.

The conditions under which the work was carried out were entirely similar to those already described.¹ The same form of cell and manometer and practically the same arrangements for constant temperature were used as in the previous investigations. The same general method of procedure was followed, except for certain slight modifications which will be described. A copper ferrocyanide membrane, deposited electrolytically by the method of Morse and Horn,² was employed.

The glucose used was that known as "*Traubenzucker Kahlbaum*." The original material contained a trace of alcohol, the odor of which was perceptible on opening the bottle. It was thoroughly pulverized and dried over calcium chloride; analysis gave the following results:

	Found. Per cent.	Calculated. Per cent.
Carbon	40.03	39.98
Hydrogen	6.83	6.71

The process of developing a membrane for quantitative measurements of pressure has already been described in detail.³ It appears from experience in this laboratory that cane sugar is better adapted for this purpose than glucose. On this account a new cell is always set up two or three times with the former before being used with the latter.

When the attempt was made to measure quantitatively the osmotic pressure of glucose solutions it quickly became ap-

¹ Am. Chem. J., 36, 1, 39.

² Ibid., 26, 80.

³ Ibid., 34, 14-19.

parent that the problem of obtaining a suitable membrane was a more serious one than in the case of cane sugar. A cell which behaves in an entirely satisfactory manner with cane sugar, maintaining a maximum pressure with little or no leakage of the dissolved substance through the membrane, may give low results with glucose and fail to maintain a maximum. Of two cells which give what have come to be regarded as correct pressures with cane sugar, the one may give the same values for glucose and the other fall low. This difference in behavior is illustrated by the following experiments:

Cell A, 0.8 N glucose.				Cell B, 0.8 N glucose.			
Time. Hours.	Pres- sure.	Theoretical gas pressure.	Differ- ence.	Time. Hours.	Pres- sure.	Theoretical gas pressure.	Differ- ence.
18	18.96	19.31	—0.35	18	19.01	19.31	—0.30
21	19.00	19.31	—0.31	22	18.88	19.31	—0.43
24	19.06	19.31	—0.25	24	18.88	19.31	—0.43
28	19.10	19.32	—0.22	29	18.90	19.32	—0.42
42	19.26	19.32	—0.06	42	18.89	19.32	—0.43
46	19.28	19.31	—0.03				

The above experiments were carried out simultaneously and with portions of the same solution. It will be observed that 18 hours after the experiments began, cell B showed a slightly higher pressure than A, but shortly afterwards the pressure in B had diminished 0.13 of an atmosphere, whereas A showed a continuous rise till the maximum was reached after 42 hours. No further increase occurred. With cane sugar, however, the two cells gave results which were concordant within the limits of experimental error, B maintaining a maximum pressure about as well as A. These results are interpreted as signifying that the membrane in cell B, while practically impermeable to cane sugar, allows glucose to pass through and consequently this cell could not be used with glucose at the time when these experiments were made. Such a membrane, however, after long use with cane sugar and being subjected repeatedly to the membrane-forming process may be developed sufficiently to give reliable results with glucose.

In fact in nearly every case a new cell gives evidence of

leakage. The amount of leakage usually decreases with use but the majority of the cells made continued to leak enough to make the results entirely unreliable, even after being set up as much as twelve or fifteen times. Out of eight cells tried, most of which were entirely satisfactory with cane sugar, two were obtained which showed practically no leakage and with these all the recorded measurements with glucose were made, with a single exception. These cells are designated A and D. Why a leaking membrane should not give the true pressure is apparent and some observations will be made on this point later in the discussion.

Shortly after this investigation was undertaken *penicillium* made its appearance in one after another of the cells being used. The glucose solution, from which the cell wall in the early stages of the development of a membrane is never entirely free, afforded a favorable environment for the growth of this fungus, the spores of which appeared to be present in the atmosphere of the laboratory in unusual quantity at the time, due perhaps to certain repairing going on in the building. Solutions of glucose exposed to the air quickly became infected. The presence of *penicillium* in the cell walls was undesirable for several reasons: 1. A possible injurious effect on the membrane was feared. The growth had gradually spread over the cell till the entire outside surface was covered with it. In all probability it had attached itself to the membrane on the inside, where the conditions were perhaps more favorable to its development and it was feared the membrane might be injured by it. The unsatisfactory behavior of the cells most infected seemed to justify this fear. 2. The presence of *penicillium* in a solution of glucose hastens fermentation.

It is obvious that for these and other reasons it was necessary to find a means of ridding the infected cells of it and preventing its reappearance. This problem, easy in itself, was complicated by the conditions under which it was necessary to work. Experience in this laboratory has strongly emphasized the fact that membranes of the character of those suitable for osmotic pressure measurements are extremely sensitive to the action of reagents, chemical or otherwise. The greatest care,

therefore, was necessary to establish thoroughly the harmlessness of the poison to be used, both as regards the membrane, as well as other parts of the cell. To prevent the re-appearance of *penicillium*, it was essential that the poison be used in all solutions, the osmotic pressures of which were to be determined. Consequently, it had to be effective in such small quantity that the pressure of the solution would not be affected appreciably by its presence. A third condition was that the agent employed should have no chemical action on glucose. We were therefore greatly restricted in the choice of a suitable remedy.

The details of the work by which a satisfactory solution of this problem was reached have already been published¹ and the reader is referred to this article. A brief resumé will suffice here.

A large number of experiments were carried out in order to determine the availability of salicylic acid, phenol, hydrocyanic acid, thymol and other substances as remedies for *penicillium*. As already stated, a solution of glucose exposed to the air of the laboratory developed a vigorous growth in from one to three days. It was found that the presence of eleven grams of salicylic per 1000 liters in a solution of glucose retarded but did not effectually prevent the growth of *penicillium* in solutions thus exposed. The growth made its appearance after six days. But this concentration of salicylic acid was found to exercise a markedly injurious effect on the membrane. A cell set up with a 0.5 normal solution of glucose containing salicylic acid failed to develop its normal pressure. The membrane could not again be brought into working condition.

Phenol also proved unsatisfactory. A glucose solution made 0.001 normal with respect to phenol developed *penicillium* after seven days' exposure.

An experiment with hydrocyanic acid was carried out in order to determine its effect on the membrane. An infected cell (D) was allowed to stand in a water solution of hydrocyanic acid for twelve hours. Certain irregularities appeared when the cell was subsequently subjected to the membrane-forming

¹ Am. Chem. J., 36, 34-39.

process, but in a short time the normal resistance was reached and with this cell some of the measurements here recorded were made.

A glucose solution made 0.001 normal with thymol remained perfectly clear for eleven days, becoming slightly cloudy on the twelfth day. By the end of this period the odor of thymol had entirely disappeared. A mass of living *penicillium* was placed in a freshly prepared solution of glucose containing thymol of the concentration given. The growth of the fungus was effectually stopped and soon it began to diminish in size, continuing to shrink for eight days. Examined under the microscope on the eighth day, it was apparently dead. On being placed in "Pasteur's liquid," however, it revived. A thymol solution of this concentration does not injure the membrane.

Of the various substances experimented with, some were fairly effective as remedies for *penicillium* but destroyed the efficiency of the membrane. One substance, hydrocyanic acid, appeared to be both effective and without any injurious effects, but the inconvenience of applying it was a serious objection to its use. Of all the poisons tried, thymol appeared to be best adapted to the purpose and it has accordingly been used throughout this investigation. All solutions employed in an osmotic pressure measurement were made 0.001 normal with respect to thymol. Thymol in this quantity seems not only to be an effective remedy for *penicillium*, but also equally effective in preventing ordinary alcoholic fermentation.

The question of dilution of the cell contents during the course of an experiment has already been discussed at some length.¹ The known causes operating to bring about dilution are the following:

1. With the form of cell used in this work, it requires from seven to fifteen minutes to close the cell at the beginning of an experiment.² During this interval water passes in from the cell wall, the amount depending on the concentration of the solution, the porosity of the wall and the "activity" of the membrane.

¹ Am. Chem. J., 36, 26, 48; 37, 327.

² Ibid., 34, 20.

2. Perhaps a slightly greater amount of dilution occurs during the opening of the cell at the end of an experiment.

3. After the cell is closed a quantity of the solvent equal in volume to the contraction of the air in the manometer enters the cell. The amount, however, is not large since the pressure is brought nearly to a maximum by mechanical means.¹

4. The distension of the cell under pressure leads to a small dilution.

5. A variable amount of dilution is brought about by slipping of the manometer through the stopper with a consequent enlargement of the capacity of the cell. The amount of this displacement of the manometer is given in the tables. It will be seen that in the later experiments the slipping was much less than in the earlier ones, due to a better reenforcement of the stopper.

6. A still further enlargement of the capacity of the cell and consequent dilution result from lack of rigidity in the stopper which serves to connect the cell and manometer. The effort was made to render the stopper as rigid as possible by the method already described.

7. In the case of a leaking membrane, of course, a further dilution comes from loss of glucose. But with cells A and D, with which all the recorded measurements were made, with one exception, the leakage was negligible.

The total amount of dilution from these causes ranged from 0.5 per cent to 3.0 per cent and was determined in each case by means of the saccharimeter. The rotations in scale divisions produced by the solution at the beginning and end of an experiment are given in the tables. By means of this instrument the concentration of a solution can be determined with a fair degree of accuracy. The rotation of the plane of polarization produced by a solution of glucose can be read to 0.05 of a scale division. The rotation given by a 0.1 weight normal solution in a two decimeter tube at 20° is 5.2 scale divisions. It will be seen, therefore, that in the case of the most dilute solution used in these experiments the concentration can be determined by means of the saccharimeter to within 1 per cent. The

¹ Am. Chem. J., 34, 22.

osmotic pressure of such a solution is 2.4 atmospheres, 1 per cent of which is 0.02 of an atmosphere. This, of course, is well within the limits of experimental error. The concentration of the normal solution can be determined to within 0.1 per cent.

It is clear then that dilution resulting from causes enumerated under 1, 3, 4, 5 and 6, *viz.*, entrance of water into the cell from whatever cause except that named under 2, undesirable as it may be, is not fatal to accuracy; provided always the cell is allowed to stay up till equilibrium is fully established. It is apparent that so long as any movement of the manometer continues, with a consequent increase in the capacity of the cell, the observed pressure can never become equal to the true osmotic pressure of the solution. Accordingly, it has been the custom in each experiment to allow a cell to remain in the bath from twenty-four to thirty-six hours after even the slightest movement of the manometer has been observed.

It is evident that dilution from cause 2 belongs to a different category from that resulting from the other causes named, since it occurs after the observations of pressure have been made. We have no means of estimating the amount of this dilution. Accordingly, it has been set down as experimental error.¹

It was said above that dilution due to entrance of the solvent into the cell does not necessarily render the results inaccurate, since the necessary correction can be applied. But if the change in concentration is due to leakage of the dissolved substance through the membrane, the case is entirely different. It is obvious that we have here a factor to deal with which can not be determined, *viz.*, the concentration of the solution in the cell wall. Moreover, equilibrium can not be established during an experiment since the concentration of the solution is constantly diminishing. On account of this continuous dilution we should not expect such a membrane to maintain a maximum pressure.

¹ Note.—In later work the attempt has been made to diminish the amount of dilution from this cause by allowing the cell to stand in a solution of glucose for a few moments just prior to beginning the operation of opening.

The actual behavior of a leaking membrane under pressure is quite different from that of one which does not leak and is just what might be predicted from theoretical considerations. In the case of a good membrane, the pressure rises steadily till a maximum is reached and after that remains constant. The concentration, as subsequently determined by means of the polariscope, corresponds to that of the solution, the osmotic pressure of which has been observed, except in so far as a further change in concentration may have taken place while the cell was being opened at the end of the experiment. But if there is leakage, the pressure rises slowly, reaches a maximum which is always low, and in a short time, usually from two to four hours, begins to fall. A membrane exhibiting such behavior is regarded as entirely unfit for quantitative measurements. It may, however, after long use, come to give reliable results. The crucial test of the trustworthiness of a cell is that it shall maintain a maximum pressure for a long period. Cell A, with which a majority of the measurements here recorded, were made, has been known to maintain a pressure of over twenty-four atmospheres for thirty-two hours with a deviation of but 0.05 of an atmosphere, which is perhaps within the limits of accuracy of reading. An examination of the records of this cell will show its remarkable power in this respect.

But even on this point the unpracticed observer is liable to be deceived. Some membranes are much more "active" than others. That is, some permit the passage of the solvent more freely than others. In all cases the rise of the mercury in the manometer becomes slower and slower as the maximum pressure is approached. In the case of a very "inactive" membrane the entrance of the solvent takes place with extreme slowness for a long period just before the maximum is reached. If such a membrane leaks slightly, the cell wall, during an experiment, is gradually becoming saturated with the dissolved substance, which diffuses but slowly into the solution on the outside. The increasing concentration of the solution in the cell wall would operate to diminish the observed pressure. At the same time water is entering from the

outside, tending to increase the pressure. Now we can easily imagine conditions to be such that for a considerable period these two processes might be in equilibrium and the pressure remain constant. Such an observed pressure, however, would not be equal to the true osmotic pressure of the solution.

Experimental details are given in the tables which follow. In Tables XXVI and XXVII will be found summaries which bring together the results in a convenient form.

Table XXVIII is inserted in order to give in convenient form a comparison of the results of glucose measurements with the results of previous measurements of the osmotic pressure of cane sugar solutions, made by Morse, Frazer, Hoffman and Kennon.¹ The table gives the ratios of the observed osmotic pressures to the calculated gas pressures at the same temperatures.

¹ Am. Chem. J., 34, 1; 36, 39.

Table V.

Original wt. normal concentration of solution, 0.3. Experiment No. 1.
 Rotation of original solution, 15°.7. Manometer used, No. 11.
 Rotation at conclusion of experiment, 15°.7. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 0.00 per cent. Cell used, D.
 Calibration units of air in manometer, 473.77. Resistance of membrane, 108,000 ohms.
 Time of setting up cell, 4.15 P.M., May 10, 1906. Initial pressure, 5.9 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Atmospheric pressure.	Corrections.			Difference between pressure found and calculated.	Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.		Liquids in manometer.	Dilution of cell contents.	Capillary depression.		
May 11										
11.00 A.M.	22°.2	21°.9	67.19	62.19	1.00	0.51	0.00	0.02	7.15	180.5
2.30 P.M.	22°.2	22°.0	67.28	62.25	1.00	0.51	0.00	0.02	7.14	180.8
5.00 P.M.	22°.3	22°.6	67.81	62.61	1.00	0.51	0.00	0.02	7.10	181.9
May 12										
10.00 A.M.	22°.2	22°.1	67.83	62.73	1.00	0.51	0.00	0.02	7.08	182.3
H = 1 Mol. Wt. Glucose = 178.74										
Mean Mol. Wt. 181.38										

Table VI.

Original wt. normal concentration of solution, 0.3. Experiment No. 2.
 Rotation of original solution, 15°.7. Manometer used, No. 11.
 Rotation at conclusion of experiment, 15°.6. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 0.64 per cent. Cell used, D.
 Calibration units of air in manometer, 473.77. Resistance of membrane, 91,000 ohms.
 Time of setting up cell, 4.30 P.M., May 14, 1906. Initial pressure, 5.9 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.			Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	
May 14								
10.40 P.M.	23°.3	24°.8	68.65	62.92	1.01	0.51	0.05	7.10
May 15								
9.00 A.M.	23°.5	24°.1	67.67	62.17	1.01	0.51	0.05	7.19
2.30 P.M.	23°.5	23°.8	67.73	62.29	1.01	0.51	0.05	7.17
May 16								
3.30 P.M.	23°.6	23°.7	67.95	62.51	1.00	0.51	0.05	7.16
Displacement of manometer = 0.52 mm.								
Dilution due to displacement of manometer = 0.07 per cent.								
					Mean Mol. Wt. 180.73			
H = 1					Mol. Wt. Glucose = 178.74.			
					Difference between pressure found and calculated.			
					Osmotic pressure corrected.			
					Theoretical gas pressure.			
					Capillary depression.			
					Difference between pressure found and calculated.			
					Osmotic pressure corrected.			
					Theoretical gas pressure.			
					Capillary depression.			
					Difference between pressure found and calculated.			
					Osmotic pressure corrected.			
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					Capillary depression.			
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					Capillary depression.			
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					Osmotic pressure corrected.			
					Theoretical gas pressure.			
					Capillary depression.			
					Difference between pressure found and calculated.			
					Osmotic pressure corrected.			
					Theoretical gas pressure.			

Table VII.

Original wt. normal concentration of solution, 0.4.
 Rotation of original solution, 20°.8.
 Rotation at conclusion of experiment, 20°.7.
 Percentage loss in concentration, 0.48 per cent.
 Calibration units of air in manometer, 442.92.
 Time of setting up cell, 4.30 P.M., May 22, 1906.
 Experiment No. 1.
 Manometer used, No. 13.
 Capillary depression, 0.02 atmosphere.
 Cell used, D.
 Resistance of membrane, 97,000.
 Initial pressure, 5.7 atmospheres.
 Corrections.

Time.	Temperature.		Volume of air in manometer.		Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.		Osmotic pressure corrected.	Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.								
May 23												
10.00 A.M.	27°.0	26°.1	48.28	44.06	1.01	0.61	0.05	0.02	9.72	9.79	-0.07	179.99
12.00 M.	26°.9	26°.2	48.36	44.12	1.01	0.61	0.05	0.02	9.71	9.78	-0.07	179.83
3.00 P.M.	26°.8	26°.3	48.61	44.35	1.01	0.61	0.05	0.02	9.67	9.78	-0.11	180.80
	H = 1		Mol. Wt. Glucose = 178.74.									
												Mean Mol. Wt. 180.21

Table VIII.

Original wt. normal concentration of solution, 0.4. Experiment No. 2.
 Rotation of original solution, 20°.8. Manometer used, No. 13.
 Rotation at conclusion of experiment, 20°.7. Capillary depression, 0.02 atmospheres.
 Percentage loss in concentration, 0.48 per cent. Cell used, D.
 Calibration units of air in manometer, 442.92. Resistance of membrane, 98,000 ohms.
 Time of setting up cell, 4.30 P.M., May 25, 1906. Initial pressure, 9.36 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Atmospheric pressure.	Corrections.			Osmotic pressure corrected.	Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.		Liquids in manometer.	Dilution of cell contents.	Capillary depression.				
May 26												
9.00 A.M.	26°.6	26°.5	48.67	44.35	0.99	0.61	0.05	0.02	9.67	9.77	-0.10	180.69
12.00 M.	26°.6	26°.6	48.77	44.43	0.99	0.61	0.05	0.02	9.66	9.77	-0.11	180.88
3.30 P.M.	26°.7	27°.0	48.97	44.55	0.99	0.61	0.05	0.02	9.63	9.78	-0.15	181.49
H = 1												Mean Mol. Wt. 181.02

Table X.

Original wt. normal concentration of solution, 0.5.
 Rotation of original solution, 25°.8.
 Rotation at conclusion of experiment, 25°.5.
 Percentage loss in concentration, 1.16 per cent.
 Calibration units of air in manometer, 441.97.
 Time of setting up cell, 12.30 P.M., May 17, 1906.

Experiment No. 2.
 Manometer used, No. 8.

Capillary depression, 0.02 atmosphere.
 Cell used, D.
 Resistance of membrane, 98,000.
 Initial pressure, 10 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.			Theoret- ical gas pres- sure.	Difference between pressure found and calculated.	Mol. wt. cal- culated from osmotic pres- sure.		
	Solution.	Air in manom- eter.	Uncor- rected.	Corrected.	Atmos- pheric pres- sure.	Liquids in manom- eter.	Dilu- tion of cell con- tent.				Capillary depres- sion.	Osmotic pres- sure cor- rected.
May 17 11.30 P.M.	23°.8	25°.7	39.78	36.35	1.00	0.66	0.14	0.02	11.98	12.10	-0.12	180.59
May 18 9.00 A.M.	24°.2	25°.6	39.63	36.22	1.00	0.66	0.14	0.02	12.02	12.12	-0.10	180.24
5.00 P.M.	24°.5	26°.6	39.89	36.34	0.99	0.66	0.14	0.02	11.99	12.13	-0.14	180.87
Displacement of manometer = 0.57 mm.										Mean Mol. Wt. 180.57		

Dilution due to displacement of manometer = 0.08 per cent.

H = 1 Mol. Wt. Glucose = 178.74.

Table XI.

Original wt. normal concentration of solution, 0.6. Experiment No. 1.
 Rotation of original solution, 30°.6. Manometer used, No. 14.
 Rotation at conclusion of experiment, 29°.45. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 3.76 per cent. Cell used, A.
 Calibration units of air in manometer, 467.21. Resistance of membrane.
 Time of setting up cell, 5.30 P.M., Jan. 25, 1906. Initial pressure, 7.0 atmospheres.
 Corrections.

Time.	Temperature.		Volume of air in manometer.		Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.	Osmotic pressure corrected.	Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.								
Jan 25												
9.00 P.M.	21°.96	22°.72	47.71									
Jan. 26												
9.15 A.M.	22°.2	22°.65	37.27									
3.40 P.M.	22°.2	22°.70	36.61									
5.00 "	22°.2	22°.80	36.62									
8.30 "	22°.2	22°.80	36.44									
Jan. 27												
10.30 A.M.	22°.2	22°.80	35.94									
3.00 P.M.	22°.2	22°.82	35.75									
4.45 "	22°.2	23°.00	35.76									
9.00 "	22°.2	22°.90	35.61									
Jan. 28												
12.00 M.	22°.3	22°.80	35.39	32.66	0.99	0.63	0.54	0.02	14.47	14.43	+0.04	178.52
8.00 P.M.	22°.7	22°.80	35.13	32.42	0.99	0.63	0.54	0.02	14.59	14.47	+0.12	177.39
Jan. 29												
9.00 A.M.	22°.7	22°.75	35.06	32.36	1.00	0.63	0.54	0.02	14.62	14.47	+0.15	176.95

Displacement of manometer = 7.29 mm.

Dilution due to displacement of manometer = 0.94 per cent.

Mean Mol. Wt. 177.62

H = 1 Mol. Wt. Glucose = 178.74.

Table XII.

Original wt. normal concentration of solution, 0.6. Experiment No. 2.
 Rotation of original solution, 30°.6. Manometer used, No. 14.
 Rotation at conclusion of experiment, 30°.0. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 1.96 per cent. Cell used, A.
 Calibration units of air in manometer, 467.21. Resistance of membrane, 68,250 ohms.
 Time of setting up cell, 5.30 P.M., Feb. 1, 1906. Initial pressure, 6.5 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.			Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.		
Feb. 1										
8.15 P.M.	22°.40	23°.40	48.23							
Feb. 2										
9.00 A.M.	22°.40	23°.36	36.55							
3.00 P.M.	22°.42	23°.36	35.95							
8.30 "	22°.43	22°.58	35.48							
Feb. 3										
9.00 A.M.	22°.45	22°.58	35.08	32.42	1.01	0.63	0.28	0.02	14.31	180.60
3.00 P.M.	22°.45	22°.42	35.08	32.41	1.01	0.63	0.28	0.02	14.31	180.60
9.00 P.M.	22°.35	22°.46	35.08	32.41	1.01	0.63	0.28	0.02	14.31	180.54
Feb. 4										
10.00 A.M.	22°.35	22°.40	34.95	32.30	1.01	0.63	0.28	0.02	14.36	179.92
H = 1	Mol. Wt. Glucose = 178.74								Mean Mol. Wt. 180.42	

Table XV.

Original wt. normal concentration of solution, 0.7. Experiment No. 2.
Rotation of original solution, 35°.5. Manometer used, No. 11.
Rotation at conclusion of experiment, 34°.5. Capillary depression, 0.02 atmosphere.
Percentage loss in concentration, 2.82 per cent. Cell used, G.
Calibration units of air in manometer, 473.77. Resistance of membrane, 218,000 ohms.
Time of setting up cell, 4.15 P.M., June 1, 1906. Initial pressure, 14 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.				Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. wt. calculated from osmotic pressure.	
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.				Osmotic pressure corrected.
June 1												
6.20 P.M.	25° 2	25° 9	30.58									
7.30 "	25° 2	25° 9	30.14									
9.00 "	25° 3	25° 8	30.15									
June 2												
10.00 A.M.	25° 3	25° 4	30.45	27.85	1.00	0.56	0.47	0.02	17.06	17.03	+0.03	
2.30 P.M.	25° 4	26° 2	30.70	28.01	1.00	0.56	0.47	0.02	16.96	17.04	-0.08	
5.30 P.M.	25° 4	26° 4	30.73	28.02	1.00	0.56	0.47	0.02	16.96	17.04	-0.08	
June 3												
10.30 A.M.	25° 6	25° 9	30.85	28.17	1.00	0.56	0.47	0.02	16.87	17.05	-0.18	

Displacement of manometer = 3.24 mm.

Dilution due to displacement of manometer = 0.21 per cent Mean Mol. Wt. 179.55

H = 1 Mol. Wt. Glucose = 178.74.

Table XVII.

Original wt, normal concentration of solution, 0.8.
 Rotation of original solution, $40^{\circ}.2$.
 Rotation at conclusion of experiment, $39^{\circ}.1$.
 Percentage loss in concentration, 2.76 per cent.
 Calibration units of air in manometer, 434.98.
 Time of setting up cell, 4.00 P.M., Nov. 15, 1906.

Original wt. normal concentration of solution, 0.8.											Experiment No. 1. Manometer used, No. 5. Capillary depression, 0.02 atmospheres. Cell used, A. Resistance of membrane, 111,000 ohms. Initial pressure, 7.2 atmospheres.
Rotation of original solution, 40°.2.											
Rotation at conclusion of experiment, 39°.1.											
Percentage loss in concentration, 2.76 per cent.											
Calibration units of air in manometer, 434.98.											
Time of setting up cell, 4.00 P.M., Nov. 15, 1906.											
Corrections.											
Time.	Temperature.	Volume of air in manometer.		Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.	Osmotic pressure corrected.	Theoretical gas pressure.	Difference between pressure found and calculated.	
		Uncorrected.	Corrected.								
Nov. 15											
8.30 P.M.	22°.8	22°.9	41.21								
11.45 "	22°.8	22°.8	27.63								
Nov. 16											
10.00 A.M.	22°.9	22°.7	25.10								
1.00 P.M.	22°.9	22°.9	25.07								
3.30 "	22°.9	22°.9	24.99								
7.30 "	22°.8	22°.9	24.94	23.00	1.00	0.64	0.53	0.02	19.10	19.30 —0.20	
Nov. 17											
10.30 A.M.	23°.0	22°.9	24.73	22.81	1.00	0.64	0.53	0.02	19.26	19.31 —0.05	
2.30 P.M.	23°.0	23°.2	24.74	22.79	1.00	0.64	0.53	0.02	19.28	19.31 —0.03	
Displacement of manometer = 9.82 mm.											
Dilution due to displacement of manometer = 1.42 per cent.											
Mean Mol. wt.										179.16	

H = 1 Mol. Wt. Glucose = 178.74.

Table XVIII.

Original wt. normal concentration of solution, 0.8. Experiment No. 2.
 Rotation of original solution, $40^{\circ}2$. Manometer used, No. 13.
 Rotation at conclusion of experiment, $39^{\circ}5$. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 1.74 per cent. Cell used, A.
 Calibration units of air in manometer, 434.93. Resistance of membrane, 108,000 ohms.
 Time of setting up cell, 4.15 P.M., Nov. 19, 1906. Initial pressure, 12.8 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.				Mol. wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Osmotic pressure corrected.	
Nov. 19									
9.45 P.M.	$22^{\circ}9$	$23^{\circ}9$	26.56						
Nov. 20									
10.30 A.M.	$23^{\circ}0$	$23^{\circ}1$	25.26						
1.00 P.M.	$23^{\circ}0$	$23^{\circ}5$	25.21						
4.15 "	$23^{\circ}1$	$23^{\circ}8$	25.10						
Nov. 21									
10.00 A.M.	$23^{\circ}1$	$22^{\circ}7$	24.79						
2.15 P.M.	$23^{\circ}1$	$23^{\circ}3$	24.77	22.82	1.00	0.64	0.34	19.06	180.53
4.30 "	$23^{\circ}1$	$23^{\circ}7$	24.72	22.74	1.00	0.64	0.34	19.13	180.43
Nov. 22									
10.00 A.M.	$23^{\circ}4$	$23^{\circ}6$	24.67	22.70	1.00	0.64	0.34	19.16	180.21
12.00 M.	$23^{\circ}5$	$23^{\circ}9$	24.65	22.66	1.00	0.64	0.34	19.19	

Displacement of manometer = 2.11 mm.

Dilution due to displacement of manometer = 0.30 per cent.

Mean Mol. Wt. 180.39

H = 1. Mol. Wt. Glucose = 178.74.

Table XIX.

Original wt. normal concentration of solution, 0.8. Experiment No. 3.
 Rotation of original solution, $40^{\circ}.2$. Manometer used, No. 6.
 Rotation at conclusion of experiment, $39^{\circ}.5$. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 1.74 per cent. Cell used, A.
 Calibration units of air in manometer, 396.89. Resistance of membrane, 155,000.
 Time of setting up cell, 4.30 P.M., Nov. 23, 1906. Initial pressure, 12.1 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.			Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.	Osmotic pressure corrected.	
Nov. 23										
7.30 P.M.	$23^{\circ}.6$	$23^{\circ}.6$	24.73							
Nov. 24										
4.20 A.M.	$23^{\circ}.6$	$23^{\circ}.3$	22.81							
11.00 "	$23^{\circ}.6$	$23^{\circ}.1$	22.61							
3.00 P.M.	$23^{\circ}.6$	$23^{\circ}.6$	22.71							
Nov. 25										
10.30 A.M.	$23^{\circ}.7$	$23^{\circ}.1$	22.44	20.68	1.00	0.67	0.34	0.02	19.22	180.05
3.00 P.M.	$23^{\circ}.6$	$23^{\circ}.4$	22.45	20.67	1.00	0.67	0.34	0.02	19.23	179.89
9.30 P.M.	$23^{\circ}.7$	$23^{\circ}.4$	22.42	20.64	1.00	0.67	0.34	0.02	19.26	179.67
Nov. 26										
10.45 A.M.	$23^{\circ}.6$	$23^{\circ}.1$	22.38	20.63	1.00	0.67	0.34	0.02	19.27	179.52
2.30 P.M.	$23^{\circ}.6$	$23^{\circ}.7$	22.42	20.63	1.00	0.67	0.34	0.02	19.27	179.52

Displacement of manometer = 2.12 mm.

Dilution due to displacement of manometer = 0.30 per cent.

Mean Mol. Wt. 179.73

H = 1 Mol. Wt. Glucose = 178.74.

Table XXI.

Original wt. normal concentration of solution, 0.9. Experiment No. 2.
 Rotation of original solution, 44°.85. Manometer used, No. 6.
 Rotation at conclusion of experiment, 44°.4. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 1.00 per cent. Cell used, A.
 Calibration units of air in manometer, 396.89. Resistance of membrane, 183,000.
 Time of setting up cell, 4.00 P.M., Dec. 3, 1906. Initial pressure, 14.7 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Corrections.				Difference between pressure found and calculated.	Mol. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncor.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.		
Dec 3										
8.00 P.M.	22°.3	22°.7	21.28							
Dec. 4										
10.00 A.M.	22°.4	22°.3	19.96							
2.00 P.M.	22°.5	22°.8	19.95	18.41	1.00	0.67	0.22	0.02	21.47	180.59
5.00 "	22°.5	22°.7	19.95	18.41	1.00	0.67	0.22	0.02	21.47	180.59
10.00 "	22°.5	23°.2	19.98	18.41	1.00	0.67	0.22	0.02	21.47	180.59
Dec. 5										
9.00 A.M.	22°.7	22°.7	19.91	18.38	1.00	0.67	0.22	0.02	21.50	180.47
2.00 P.M.	22°.7	23°.4	19.94	18.36	1.00	0.67	0.22	0.02	21.53	180.21

Displacement of manometer = 0.98 mm.

Dilution due to displacement of manometer = 0.12 per cent.

Mean Mol. Wt. 180.49

H = 1 Mol. Wt. Glucose = 178.74.

Table XXIII.

Original wt. normal concentration of solution, 1.0.
 Rotation of original solution, $49^{\circ}4$.
 Rotation at conclusion of experiment, $48^{\circ}95$.
 Percentage loss in concentration, 0.91 per cent.
 Calibration units of air in manometer, 434.93.
 Time of setting up cell, 11.30 A.M., Dec. 12, 1906.

Time.	Temperature.		Volume of air in manometer.		Corrections.				Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.	Atmospheric pressure.	Liquids in manometer.	Dilution of cell contents.	Capillary depression.	
Dec. 12									
8.45 P.M.	$22^{\circ}0$	$22^{\circ}2$	19.53						
Dec. 13									
10.00 A.M.	$22^{\circ}0$	$21^{\circ}8$	19.46						
4.45 P.M.	$22^{\circ}0$	$22^{\circ}7$	19.46	17.96	1.00	0.65	0.22	0.02	24.11
11.00 "	$22^{\circ}1$	$22^{\circ}2$	19.44	17.97	1.00	0.65	0.22	0.02	24.09
Dec. 14									
10.45 A.M.	$22^{\circ}3$	$23^{\circ}0$	19.44	17.92	1.01	0.65	0.22	0.02	24.16
2.15 P.M.	$22^{\circ}3$	$22^{\circ}6$	19.45	17.96	1.01	0.65	0.22	0.02	24.11
5.00 "	$22^{\circ}3$	$22^{\circ}5$	19.44	17.96	1.01	0.65	0.22	0.02	24.11

Displacement of manometer = 1.49 mm.

Dilution due to displacement of manometer = 0.20 per cent.

Mean Mol. Wt. 178.46

H = 1 Mol. Wt. Glucose = 178.74.

Table XXV.

Original wt. normal concentration of solution, 1.0. Experiment No. 3.
 Rotation of original solution, $49^{\circ}.4$. Manometer used, No. 6.
 Rotation at conclusion of experiment, $48^{\circ}.55$. Capillary depression, 0.02 atmosphere.
 Percentage loss in concentration, 1.72 per cent. Cell used, A.
 Calibration units of air in manometer, 396.89. Resistance of membrane, 185,000 ohms.
 Time of setting up cell, 12.30 P.M., Dec. 15, 1906. Initial pressure, 13.9 atmospheres.

Time.	Temperature.		Volume of air in manometer.		Atmospheric pressure.	Corrections.			Theoretical gas pressure.	Difference between pressure found and calculated.	Mol. Wt. calculated from osmotic pressure.
	Solution.	Air in manometer.	Uncorrected.	Corrected.		Liquids in manometer.	Dilution of cell contents.	Capillary depression.			
Dec. 15											
6.00 P.M.	$22^{\circ}.1$	$22^{\circ}.2$	18.28								
8.15 "	$22^{\circ}.1$	$22^{\circ}.1$	18.07								
Dec. 16											
9.00 A.M.	$22^{\circ}.1$	$21^{\circ}.9$	18.00								
1.30 P.M.	$22^{\circ}.1$	$21^{\circ}.8$	18.03								
10.00 "	$22^{\circ}.1$	$22^{\circ}.0$	17.96	16.62	1.00	0.67	0.41	0.02	23.98	-0.09	179.41
Dec. 17											
10.15 A.M.	$22^{\circ}.1$	$22^{\circ}.1$	17.91	16.56	1.00	0.67	0.41	0.02	24.06	-0.01	178.81
12.30 P.M.	$22^{\circ}.1$	$22^{\circ}.1$	17.93	16.58	1.00	0.67	0.41	0.02	24.04	-0.03	178.96
5.00 "	$22^{\circ}.1$	$22^{\circ}.2$	17.94	16.59	1.00	0.67	0.41	0.02	24.02	-0.05	179.11

Displacement of manometer = 1.24 mm.

Dilution due to displacement of manometer = 0.17 per cent.

Mean Mol. Wt. 179.07

H = 1 Mol. Wt. Glucose = 178.74.

Table XXVII.—*Determination of the Osmotic Pressure of Glucose.*

Series I., 1906. Summary of Results.

Weight normal con- centra- tion.	No. of ex- peri- ment.	Tempera- ture of solution.	Observed osmotic pressure. Atmos- pheres.	Theoretical gas pres- sure at same tem- perature. Atmos- pheres.	Difference between osmotic and gas pres- sure.	Molecular weight calculated from osmotic pres- sure.	Mean molecular weight for each concentration.
0.1	1	24°.10	2.39	2.42	—0.03	181.40	
"	2	25°.10	2.42	2.43	—0.01	179.83	180.62
0.2	1	24°.10	4.76	4.85	—0.09	181.77	
"	2	24°.93	4.77	4.86	—0.09	182.10	181.94
0.3	1	22°.20	7.12	7.22	—0.10	181.38	
"	2	23°.48	7.17	7.25	—0.08	180.73	181.06
0.4	1	26°.90	9.70	9.78	—0.08	180.21	
"	2	26°.60	9.65	9.77	—0.12	181.02	180.62
0.5	1	21°.86	12.07	12.03	+0.04	178.12	
"	2	24°.17	12.00	12.12	—0.12	180.57	179.35
0.6	1	22°.57	14.56	14.46	+0.10	177.62	
"	2	22°.40	14.32	14.40	—0.08	180.42	
"	3	22°.30	14.29	14.45	—0.16	180.83	179.62
0.7	1	22°.26	16.82	16.85	—0.03	179.18	
"	2	25°.43	16.96	17.04	—0.08	179.55	
"	3	22°.70	16.75	16.88	—0.13	180.16	179.63
0.8	1	23°.00	19.27	19.31	—0.04	179.16	
"	2	23°.28	19.16	19.33	—0.17	180.39	
"	3	23°.64	19.25	19.35	—0.10	179.73	179.76
0.9	1	23°.80	21.64	21.80	—0.16	179.87	
"	2	22°.58	21.49	21.70	—0.21	180.49	
"	3	23°.10	21.63	21.74	—0.11	179.60	179.99
1.0	1	22°.20	24.12	24.08	+0.04	178.46	
"	2	22°.60	24.00	24.11	—0.11	179.60	
"	3	22°.10	24.03	24.07	—0.04	179.07	179.04
H = 1 Mol. Wt. Glucose = 178.74			Mean Mol. Wt. 180.08				

Table XXVIII.—Ratio of Observed Osmotic to Calculated Gas Pressure at the Same Temperature, the Volume of the Gas Being That of the Solvent in the Pure State.

Weight normal concentration.	No. of experiment.	Cane Sugar.				Glucose. Series I.	
		Series I.		Series II.		Series I.	
		Temperature.	Ratio.	Temperature.	Ratio.	Temperature.	Ratio.
0.1	1	18°.85	1.021	24°.06	1.037	24°.10	0.988
"	2	18°.71	1.017	24°.23	1.049	25°.10	0.996
0.2	1	20°.59	0.987	20°.90	0.985	24°.10	0.981
"	2	20°.91	0.998	21°.38	0.996	24°.93	0.981
"	3			21°.77	1.000		
0.25	1	23°.45	1.005				
"	2	21°.46	0.987				
0.3	1	19°.28	1.001	21°.67	1.004	22°.20	0.986
"	2	17°.65	1.007	19°.88	1.006	23°.48	0.989
0.4	1	18°.81	0.990	21°.63	1.003	26°.90	0.992
"	2	20°.94	1.004	22°.15	1.006	26°.60	0.988
0.5	1	20°.84	0.993	22°.62	1.000	21°.86	1.003
"	2	20°.32	1.006	23°.70	1.010	24°.17	0.990
0.6	1	21°.38	0.984	24°.38	1.013	22°.57	1.007
"	2	24°.45	0.984	24°.70	1.010	22°.46	0.994
"	3			24°.10	1.016	22°.30	0.988
0.7	1	20°.14	0.993	23°.64	1.000	22°.26	0.998
"	2	24°.62	0.992	23°.90	1.002	25°.43	0.995
"	3					22°.70	0.992
0.8	1	17°.89	1.009	23°.60	0.997	23°.00	0.998
"	2	19°.56	1.012	23°.69	1.002	23°.28	0.991
"	3					23°.64	0.995
0.89101	1	19°.34	0.987				
0.9	1	19°.84	1.006	24°.79	0.998	23°.80	0.993
"	2			24°.76	1.002	22°.58	0.990
"	3					23°.10	0.995
1.0	1	23°.32	1.012	23°.56	1.010	22°.20	1.002
"	2	22°.44	1.005	24°.58	0.988	22°.60	0.995
"	3	21°.60	1.003			22°.10	0.998

From the foregoing results it is clear that the rule as formulated by Morse and Frazer¹ for cane sugar holds equally well for glucose. The rule has been stated as follows: *Glucose, in aqueous solution, at temperatures in the vicinity of 20°, exerts an osmotic pressure equal to the pressure which a molecular equivalent quantity of a gas would exert if its volume were reduced at the same temperature to that of the solvent in the pure state.*²

¹ Am. Chem. J., 34, 93; 36, 87.

² Ibid., 37, 357.

BIOGRAPHICAL.

Benjamin F. Lovelace was born in Edgefield County, South Carolina, February 27, 1876. His early education was received in a private school in that state and in the public schools of Florida. He entered the Florida Conference College in September, 1892, and graduated with the A.B. degree in May, 1896.

He has taught as follows: Mathematics, Florida Conference College, 1896-1899; mathematics and chemistry, Tuscaloosa (Alabama) Female College, 1899-1902; chemistry (assistant), University of Alabama, 1902-1904. While teaching in Tuscaloosa he was for five years a special student at the University of Alabama and obtained the B.S. degree in 1904.

In October, 1904, he entered the Johns Hopkins University as a graduate student in chemistry, his subordinate subjects being physical chemistry and physics.

